Patent Application of

Naum Sapozhnikov

for

TITLE: COMPOSITE CONCRETE PAVEMENT FOR HIGHWAYS AND STREETS WITH THE ENRICHED QUARRY LIMESTONE WASTE AS A COARSE AGGREGATE FOR CONCRETE OF SUBBASE AND/OR LOWER LAYER

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FEDERALLY SPONSORED RESEARCH

Not Applicable

SEQUENCE LISTING PROGRAM

Not Applicable

BACKGROUND – FIELD OF INVENTION

Present invention relates to the design and construction of highway and street concrete pavements.

BACKGROUND OF INVENTION-THE PRIOR ART

Composite concrete pavements with surface course of normal concrete and subbase or lower layer of lean concrete are used widely in the US building practice to reduce the cost of pavement. The design procedure of Portland Cement Association Engineering Bulletin (Thickness Design for Concrete Highway and Street Pavements, Portland Cement Association, EB109P) indicates a

thickness for two-layer concrete pavement equivalent to a given thickness of normal concrete. Lean concrete of modulus of rupture (MR) in the range from 150 to 450psi for subbase and lower layer monolithic with normal concrete of surface course is taken for design charts of composite pavement.

Design procedure of the normal concrete pavement results in the certain value of normal concrete thickness. The sense of composite pavements of the identical capacity is in the reduction of consumption of normal concrete with high cost crushed granite as a coarse aggregate by replacing of a part of this concrete by subbase or lover layer cheaper concrete. Design procedure of composite concrete pavement should result in the equivalent normal concrete thickness of the same value as for the corresponding normal concrete pavement. The choice of flexural strength for subbase and lover layer of composite concrete pavement is determined by the merely economical reasons. Increase of flexural strength of concrete of subbase or lower layer means the increase of equivalent thickness of normal concrete pavement and possibility of corresponding reduction of thickness of normal concrete surface course of this pavement. Increase of equivalent normal concrete thickness of composite pavement due to increase of flexural strength of concrete of subbase without changing of the thickness of subbase can be considered approximately as a measure of possible reduction of thickness of surface course of this pavement.

Design chart for composite concrete pavement with lean concrete subbase of modulus of rupture in the range from 150 to 450psi is presented on the Fig.B1, Appendix 2 of said Portland Cement Association Engineering Bulletin. It allows estimation of equivalent normal concrete thickness of composite concrete pavement corresponding to the different combinations of thickness of lean concrete subbase and normal concrete surface course of pavement.

The values of equivalent normal concrete thickness of pavement corresponding to the lean concrete 4-inch thickness subbase of modulus of rupture in the range from 150 to 450psi and values of thickness of surface course in the range from 7 to 10 inches were estimated according to this design chart. It allows estimation of the change of equivalent thickness of composite pavement

depending on the change of lean concrete flexural strength of subbase. Moreover, relative increase of this thickness depending on the increase of modulus of rupture of lean concrete of subbase were carried out, equivalent normal concrete thickness corresponding to the value of modulus of rupture equal to 150 psi being considered as 1,0. Results of these calculations are presented in Table 1.

Table 1

Thickness of normal concrete surface course (inch)	Modulus of rupture of normal concrete of surface course in the range 600 to 700 psi Modulus of rupture of 4-inch thickness lean concrete subbase, psi				Modulus of rupture of normal concrete of surface course in the range 500 to 600 psi Modulus of rupture of 4-inch thickness lean concrete subbase, psi			
	150	250	350	450	150	250	350	450
	Equivalent normal concrete thickness of composite pavement (inch) and relative increase of this thickness depending on the increase of modulus of rupture of lean concrete of subbase (equivalent normal concrete thickness corresponding to the value of modulus of rupture equal to 150 psi is considered as 1,0)							
7	8.5/1.0	9.1/1.07	9.5/1.12	9.9/1.2	8.6/1.0	9.2/1.07	10.0/1.16	10.4/1.2
8	9.6/1.0	10.2/1.07	10.7/1.11	11.2/1.16	9.8/1.0	10.5/1.07	11.0/1.12	11.5/1.17
9	10.6/1.0	11.3/1.07	11.8/1.11	12.3/1.16	10.9/1.0	11.5/1.06	12.2/1.12	12.6/1.16
10	11.6/1.0	12.4/1.07	12.9/1.11	13.4/1.16	11.9/1.0	12.6/1.06	13.4/1.12	13.8/1.16

As can be seen from the Table 1, increase of equivalent normal concrete thickness of composite pavement due to increase of modulus of rupture of concrete of subbase from 150 to 450 psi constitutes at least 15 %. It can be considered as estimation of corresponding reduction of the thickness of normal concrete surface course.

Moreover, efficiency of composite pavement with lean concrete subbase can be estimated as a ratio of equivalent normal concrete thickness of composite pavement to physical one (thickness of subbase plus thickness of surface course). Estimations of this ratio corresponding to the values of modulus of rupture of concrete in the range from 150 to 450psi, the values of thickness of subbase equal to 4, 5, and 6 inches, and the values of normal concrete surface course in the range from 7 to 11 inches were calculated according to design chart Fig.B1 of said Engineering Bulletin. Average estimations of this ratio are presented in the Table 2.

Table 2

Thickness of lean concrete subbase in.	Modulus of rupture of normal concrete of surface course in the range 600 to 700 psi. Modulus of rupture of lean concrete of subbase, psi				Modulus of rupture of normal concrete of surface course in the range 500 to 600 psi. Modulus of rupture of lean concrete of subbase, psi			
	150	250	350	450	150	250	350	450
	Ratio between equivalent normal concrete thickness of composite concrete pavement and physical one of this pavement							
4	0.803	0.856	0.902	0.936	0.829	0.877	0.923	0.962
5	0.786	0.835	0.897	0.912	0.810	0.858	0.906	0.950
6	0.707	0.819	0.864	0.864	0.793	0.840	0.895	0.944

It is evident that the efficiency of the use of lean concrete for composite concrete pavements increases with the reduction of the difference between the values of modulus of rupture of normal concrete of surface course and the lean concrete of subbase. The compressive and flexural strengths of lean concrete are determined to a great extent by the quality of coarse aggregate. Lean concrete can be produced when local or recycled, relatively cheap coarse aggregates are available; the cost of concrete is determined to a large degree by the cost of coarse aggregate. The use of cheap small grains coarse aggregates is the one of the way of obtaining of lean and not only lean concrete. The name of Russian standard GOST 26633 is “Normal and small grains concrete”.

Small grains crushed limestone is one of the cheapest aggregates. According to the US Geological Survey, crushed limestone constitutes 71% of total weight of coarse aggregates for concrete produced in USA. This product of grading finer than 9.5mm usually is not used as a coarse aggregate. Utilization of great deposits of crushed limestone finer than 9.5mm and especially finer than 4.75mm (from 10 to 25% of the total volume of quarrying) are urgent for aggregate industry. The object of design of composite concrete pavements is to obtain the highest concrete strength of subbase and lower layer of this pavement with the cheapest coarse aggregate and with the moderate consumption of cement.

OBJECTS AND ADVANTAGES

The main object of the present invention is to obtain composite concrete pavement for highways and streets with the thickness of normal concrete surface course determined by requirements for the abrasion resistance and lower layer of concrete with the coarse aggregate defined as enriched limestone waste, lower layer being monolithic with the surface course. Compressive and flexural strength of concrete of lower layer can be at least close to that for concrete of surface course. Concrete of lower layer requires consumption of cement, which is less or at least close to that for concrete of surface course of the same compressive strength with crushed granite as a coarse aggregate.

Another important object of the present invention is to obtain composite concrete pavement for highways and streets with the surface course of thickness determined by requirements for the abrasion resistance and subbase of concrete with the coarse aggregate defined as enriched limestone waste. Compressive and flexural strength of concrete of subbase can be at least close to that for concrete of surface course. Concrete of subbase requires consumption of cement, which is less or at least close to that for concrete of surface course of the same compressive strength with crushed granite as a coarse aggregate.

Still another important object of the present invention is to obtain composite concrete pavement for highways and streets with the thickness of normal concrete surface course determined by determined by requirements for the abrasion resistance, lower layer and subbase of concrete with the coarse aggregate defined as enriched limestone waste. Compressive and flexural strength of concrete of lower layer and subbase can be at least close to that for concrete of surface course. Concrete of lower layer and subbase requires consumption of cement, which is less or at least close to that for concrete of surface course of the same compressive strength with crushed granite as a coarse aggregate.

The most important object of present invention is to obtain concrete with the coarse aggregate as a processed by-product of regular sizes crushed limestone manufacture defined as enriched limestone waste. Grading of this aggregate is intermediate between coarse and fine aggregates in Terminology of ASTM C125. Compressive and flexural strength of concrete with this coarse aggregate should be higher or at least close to that for concrete of the same consumption of cement with crushed granite of regular sizes number as a coarse aggregate.

The main advantage of present invention is the feasibility of obtaining of concrete with the values of specified compressive strength and modulus of rupture up to 5,000 psi and more than 750 psi, respectively, using processed by-product of manufacture of crushed limestone of ordinary sizes defined as enriched limestone waste as a coarse aggregate. It does not require excessive consumption of cement; amount of consumed cement for this concrete is less or at least close to that for concrete of the same compressive and flexural strength with crushed granite and crushed limestone of the ordinary sizes as a coarse aggregate.

Another important advantage of present invention is the possibility of construction of composite concrete pavement using very cheap concrete of compressive strength and modulus of rupture up to 5,000 psi and more than 750 psi, respectively, with the enriched limestone waste as a coarse aggregate for of subbase and/or lower layer of this pavement. Consumption of cement for concrete with the enriched limestone waste as a coarse aggregate is less or at least close to that for concrete of surface course of the same compressive strength with crushed granite of regular sizes as a coarse aggregate. Compressive and flexural strength of concrete for subbase and/or for lower layer can be not less than that for surface course of this pavement. As a result, equivalent normal concrete thickness of composite concrete pavement can be close to physical one of this pavement.

Yet another important advantage of present invention is the possibility to use limestone quarry waste as a coarse aggregate of concrete instead of high-quality aggregate. It allows very profitable utilization of great deposits of crushed limestone finer than 9.5mm usually estimated as limestone

quarry waste and especially aggregate finer than 4.75mm. In so doing the volume of utilized aggregate finer than 4.75mm should constitutes at least 1/3 of the volume of utilized aggregate finer than 9.5mm. Utilization of limestone waste enables to reduce quarrying of high-quality aggregate with corresponding conservation of environment.

SUMMARY OF INVENTION

Composite concrete pavement includes normal concrete surface course of thickness determined by requirements for the abrasion resistance of surface and subbase or subbase and lower layer. Concrete of subbase and lower layer with coarse aggregate defined as enriched limestone waste of grading intermediate between coarse and fine aggregates in Terminology of ASTM C125 is characterized by specified compressive strength fc' and modulus of rupture (MR) up to 5,000 and more than 750 psi, respectively. This aggregate is processed by-product of manufacture of crushed limestone of ordinary Sizes number 56, 57, 6, and 67 with the rated dimensions 25- 9.5 mm, 25-4.75 mm, 19- 9.5 mm, and 19-4.75 mm, respectively. The aim of enrichment of limestone quarry waste is the reduction of small sizes of grains. Enrichment of this aggregate should be carried out by washing or screening, or by combination of washing and screening. Method of enrichment depends on the grading of aggregate and should be selected by economical reasons.

Limestone quarry waste as a raw material for enrichment should be finer than 9.5mm but coarser than 4.75mm. The amount of aggregate finer than 4.75 mm (Sieve No.4) before enrichment should be at least the value of the same order as for the least Size of coarse aggregate number 89 according to ASTM C33, and it should be not less than 1/3 of the total weight of aggregate. After enrichment the main part of aggregate finer than 4.75mm should be coarser than 2.36mm. The amount of aggregate finer than 2.36 mm (Sieve No. 8) should not exceed about 10%; the amount of aggregate finer than 1.18mm (Sieve No. 16) should not exceed about 7 %; the amount of aggregate finer than 300μm (Sieve No. 50) should not exceed about 2 %.

Handling and transportation of enriched limestone waste from a quarry to the aggregate bin of a concrete plant causes inevitable breakdown of aggregate. Due to weather effects and other impacts such as loading and discharge, grading of enriched limestone waste may become unpredictable. However, few parameters of grading of enriched limestone waste after transportation from a quarry to the aggregate bin of a concrete plant should be controlled in the framework of the present invention. The amount of aggregate finer than 4.75 mm (Sieve No.4) should be less than that for largest Size of fine aggregate number 9 according to ASTM C 33. It should be close to but not exceed 2/3 of the total weight of aggregate. The amount of aggregate finer than 300μm (Sieve No. 50) should not exceed about 3.0%. Grading of enriched limestone waste after transportation from a quarry to the aggregate bin of a concrete plant can be considered as intermediate between coarse and fine aggregates in the Terminology of ASTM C125.

The compressive and flexural strength of the concrete of the subbase and the lower layer with enriched limestone waste as a coarse aggregate can be not less than that for normal concrete of the surface course of this pavement. The amount of consumed cement for subbase and lower layer is less or at least close to that for normal concrete of the same compressive strength with crushed granite of regular sizes as a coarse aggregate. As a result of the use of concrete with the different cost but with the same compressive and flexural strength for different parts of composite pavement, the equivalent normal concrete thickness of this pavement is close to the physical one.

Concrete of specified compressive strength and modulus of rupture up to 5,000 more than 750psi, respectively, with enriched limestone waste as coarse aggregate is very cheap and efficient. The use of this concrete for composite concrete pavement means considerable reduction of initial cost of construction this pavement and increase of competitiveness as compared with asphalt pavement.

Moreover, the use of concrete with this coarse aggregate allows very profitable utilization of great deposits of crushed limestone finer than 9.5mm usually estimated as limestone quarry waste

and especially aggregate finer than 4.75mm. In so doing the volume of utilized aggregate finer than 4.75mm should constitutes at least 1/3 of the utilized volume of aggregate finer than 9.5mm. Utilization of limestone waste enables to reduce quarrying of high-quality aggregate with corresponding conservation of environment.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

Composite concrete pavement includes normal concrete surface course with the thickness determined by the requirements for abrasion resistance of surface and subbase and/or lower layer monolithic with the surface course. Processed by-product of manufacture of crushed limestone of regular sizes defined conventionally as enriched limestone waste of grading intermediate between the coarse and fine aggregates in the Terminology ASTM C125 is used as a coarse aggregate for concrete of subbase and/or lower layer of this pavement. This concrete is characterized by the specified compressive strength f_c' and modulus of rupture (MR) up to 5,000 and more than 750 psi, respectively. Consumption of cement for concrete with enriched limestone waste of this grading as a coarse aggregate is less or at least close to that for concrete of the same compressive and flexural strength with crushed granite of regular sizes as a coarse aggregate.

Portland Cement Association Engineering Bulletin (Thickness Design for Concrete Highway and Street Pavements, Portland Cement Association, EB109P) provides thickness design of composite concrete pavement with lean concrete of subbase and lower layer of modulus of rupture in the range of 150-450 psi. The use of enriched limestone waste of grading intermediate between the coarse and fine aggregates in the Terminology ASTM C125 as a coarse aggregate of concrete for subbase and lower layer of composite concrete pavement allows to increase flexural strength of these parts of pavement. In spite of the differences of composition and cost of concrete for surface course and subbase and/or lower layer their compressive and flexural strengths can be similar. In this case equivalent normal concrete thickness of this composite pavement determined according to said Engineering Bulletin is close to physical one.

Enriched limestone waste is cheap coarse aggregate, and it considerably determines the cost of concrete. The use the concrete with this coarse aggregate allows to reduce initial cost of construction and should make concrete pavements more competitive as compared with the asphalt pavements.

OPERATION OF PREFERRED EMBODIMENT

Portland Cement Association Engineering Bulletin (Thickness Design for Concrete Highway and Street Pavements, Portland Cement Association, EB109P) contents design charts for composite concrete pavement with subbase and lower layer of lean concrete with the values of modulus of rupture in the range of 150-450 psi. This design procedure indicates a thickness for two-layer concrete pavement equivalent to a given thickness of normal concrete. The efficiency of composite pavement can be estimated as a ratio of equivalent normal concrete thickness of pavement to the physical one of this pavement.

Said Portland Cement Association Engineering Bulletin does not provide thickness design of composite concrete pavement with modulus of rupture of subbase or lover layer higher than 450psi. However modulus of rupture of concrete with enriched limestone quarry waste as a coarse aggregate for subbase and lower layer of composite pavement can exceed 450psi. Moreover, it can be not less than that for the normal concrete of surface course of this pavement. In this case equivalent normal concrete thickness of composite pavement is equal to the physical one of this pavement, and the ratio of equivalent normal concrete thickness of pavement to the physical one is estimated as unity.

Equivalent normal concrete thickness of composite pavement with modulus of rupture of concrete for subbase and lower layer intermediate between 450psi and that for surface course should be estimated by the ratio of equivalent normal concrete thickness of this pavement to the its physical one. This ratio is in the range from that corresponding to the composite concrete pavement of value of modulus of rupture of concrete of subbase or lower layer equal to 450psi (Design charts Fig. B1 and B2 of said Engineering Bulletin) to the unity. The ratio of equivalent normal concrete thickness to the its physical one for pavement of modulus of rupture of subbase and lover layer, which is

higher than 450psi but less than modulus of rupture of surface course, should be estimated by interpolation.

For example, equivalent normal concrete thickness of composite pavement of the 5-inches thickness subbase of concrete of modulus of rupture equal to 450psi and 10-inches thickness normal concrete surface course of modulus of rupture equal to 700psi can be estimated as 14 inches. The ratio of the equivalent normal concrete thickness to the physical one of this pavement (15 inches) is equal to 0.933. It is necessary to determine the equivalent normal concrete thickness of composite concrete pavement of the same dimensions and the same flexural strength of surface course but with the concrete of subbase of modulus of rupture equal to 600psi. It should be estimated by the ratio of equivalent normal concrete thickness of this pavement to its physical one. This ratio should be estimated by interpolation between that corresponding to the composite concrete pavements of the values of modulus of rupture of concrete of subbase or lower layer equal to 450 and 700psi. This ratio can be estimated as 0.933+(1-0.933)*(600-450)/(700-450)=0.973, while the equivalent normal concrete thickness of pavement should be estimated as 15*0.973=14.6 inches.

The choice of the value of modulus of rupture of concrete of subbase and lower layer is determined by economical reasons.

DETAILED DESCRIPTION OF ADDITIONAL EMBODIMENT

Concrete of subbase and/or lower layer of composite concrete pavement is produced with the use of coarse aggregate defined as enriched limestone quarry waste of grading intermediate between coarse and fine aggregates in Terminology of ASTM C125. Physical properties of this coarse aggregate should be in accordance with requirements of the ASTM C33. This concrete is characterized by the specified compressive strength f_c' and modulus of rupture (MR) up to 5,000 and more than 750 psi, respectively. Compressive strength of this concrete should be higher than that for concrete of the same consumption of cement with crushed limestone of the Size number 89 as a coarse aggregate. Moreover, compressive strength of this concrete should be higher or at least close

to that for concrete of the same consumption of cement and twice as high consumption of admixture with crushed granite of regular sizes as a coarse aggregate. Flexural strength of this concrete is higher than that for concrete of the same consumption of cement with crushed granite of regular sizes as a coarse aggregates.

Limestone quarry waste is a by-product of manufacture of crushed limestone of regular sizes mainly numbers 56, 57, 6 and 67 of the rating dimensions 25- 9.5 mm, 25-4.75 mm, 19- 9.5 mm and 19-4.75 mm, respectively. As a raw material for enrichment it should be finer 3/8 in.(9.5 mm) and coarser than 4.75mm (Sieve No.4). Proportion between the amounts of aggregate finer and coarser than 4.75mm before enrichment is very important; the problem of utilization of aggregate finer than 4.75 mm is more urgent than that for part of this by-product coarser than 4.75mm. Moreover, aggregate finer than 4.75 mm is considerably cheaper than part of this by-product coarser than 4.75mm. According to the invention, the amount of aggregate finer than 4.75 mm at the quarry before enrichment should be at least the value of the same order as that for the least Size of coarse aggregate number 89 according to the ASTM C33 and not less than about 1/3 of the total weight of aggregate.

Proportion between the amounts of aggregate finer and coarser than 4.75mm before enrichment should be determined taking into account an inevitable breakdown of this aggregate due to dry enrichment by screening and especially due to transportation of this aggregate to concrete plant. The breakdown of aggregate is caused by weather conditions (rain, frost, thawing) and handling of this aggregate (loading, discharge and other actions during transportation from quarry to aggregate bin of concrete plant). Due to the influence of scale effect this breakdown relates mainly to the portion of aggregate coarser than 4.75mm. As a result, amount of aggregate finer than 4.75mm in the aggregate bin of concrete plant can be considerably higher than at the quarry. The amount of this fraction in the aggregate bin of concrete plant should be close to but not exceed 2/3 of the total weight of aggregate. Transportation of the very vulnerable enriched limestone waste of 10 percents

water-absorption from quarry to the concrete plant under adverse weather conditions results in the doubling the amount of aggregate finer than 4.75mm-from 1/3 to 2/3 of the total amount of aggregate. Less water-absorption of aggregate and actual reduction of the quantity of adsorbed water means less breakdown of aggregate and more similar proportions between amounts of aggregate finer and coarser than 4.75mm at the quarry and in the aggregate bin.

Enrichment of this by-product can be carried out by washing or screening, or by combination of washing and screening separately for parts finer and coarser than 4.75mm with consequent mixing of these parts or without this separation. The aim of enrichment of limestone waste is reduction of small size grains and to obtain the desirable proportion between the parts of aggregate. The choice of method of enrichment depends on the results of sieve analysis of this aggregate, water-absorption of aggregate, and required grading of aggregate after enrichment.

Due to the enrichment of limestone waste, the amount of small Sizes of grains at the quarry should be reduced. The amount of aggregate finer than 2.36 mm (Sieve No. 8) should not exceed about 10%, the amount of aggregate finer than 1.18mm (Sieve No. 16) should not exceed about 7 %, the amount of aggregate finer than 300μm (Sieve No. 50) should not exceed about 2 %. The main part of aggregate finer than 4.75mm should be coarser than 2.36mm. The amount of aggregate coarser than 4.75mm after enrichment should be higher than 1/3 of the total weight of aggregate, and this excess is determined by the volume of inevitable breakdown of aggregate during the transportation to the aggregate bin of concrete plant. There are requirements of present invention for control of grading of enriched limestone waste as a coarse aggregate for concrete at the quarry after enrichment.

Transportation of enriched limestone waste from quarry to the aggregate bin of concrete plant causes the reduction of amount of large size grains and a corresponding increase of the amount of small size grains since large size grains are more vulnerable. It can make grading of this aggregate variable and even unpredictable. However, few parameters of grading of enriched limestone waste

after transportation from a quarry to the aggregate bin of a concrete plant should be controlled in the framework of the present invention. The amount of aggregate finer than 4.75 mm (Sieve No.4) should be less than for the largest Size of fine aggregate number 9 according to ASTM C33. It should be close to but not exceed 2/3 of the total weight of aggregate. The main part of aggregate finer than 4.75mm should be coarser than 2.36mm. The amount of aggregate finer than 300μm (Sieve No. 50) should not exceed about 3.0 %. Grading of enriched limestone waste as a whole after transportation can be considered borderline between coarse and fine aggregates in Terminology of ASTM C125, i. e. between grading of Sizes number 89 and 9 according to ASTM C33.

Experimental investigations of the washed by-product of manufacture of crushed limestone as a coarse aggregate for concrete were carried out in Moscow Institute of Concrete and Reinforced Concrete (NIIZHB). These investigations were necessary due to the shortage and high cost of crushed granite as a coarse aggregate in the Moscow region; it was attempt to find more cheap coarse aggregate at least for concrete of middle strength. Enriched limestone waste product of Lavsk quarry of Lipetsk region (350 km South East of Moscow) was used for this purpose. This is the washed by-product of the manufacture of crushed limestone of regular Russian Sizes 5-20 mm (the closest American Size is number 67, 19-4.75 mm) and 20-40mm defined as Russian fraction 3-10 mm.

Samples were taken from a large volume cone according to the Russian standard (very close to the similar ASTM standard) and were delivered to Institute laboratory in bags retaining quarry grading after enrichment of this aggregate. The crushing strength of limestone waste was estimated by compressing in a 150 mm-diameter cylinder. Loss of weight of tested samples made up 17%. According to the Russian building code, this loss of weight corresponds to compressive strength of coarse aggregate equal to 600 kgf /cm^2 (near 8500 psi). This is half as much as minimum strength of crushed granite Grades 1200-1400 kgf /cm^2.

Water-absorption of limestone waste is equal to 10%; specific gravity is equal to 2.46 g/cm^3; bulk density is equal to 1390 kg/m^3; the voids volume is estimated as 43%.

Frost resistance of limestone waste was determined by the test of samples in the solution of sodium sulfate with subsequent drying. The loss of mass after 10 cycles made up 10%. According to the Russian building code, frost resistance of limestone waste is estimated as Grade F50. The content of dissoluble silica in limestone waste makes up 21 milliliters per liter.

Samples of aggregate were dried to constant weight. Averaged results of sieve analysis of enriched limestone waste as a coarse aggregate defined as fraction 3-10 mm according to the Russian building code are presented in Table 3 in the form adopted in the US building practice.

Table 3

	Dimensions of Square Openings (mm)				
	12.50	10.00	5.00	2.50	Less than 2.5
Sieve residue (%)	0.75	0.75	64.00	25.50	9.0
Amount finer than each laboratory sieve (%)	99.25	98.5	34.50	9.00	-

As can be seen from Table 3, grading of this aggregate considered as a quarry grading is close to that for Size number 89 as the least Size of coarse aggregate according to ASTM C 33. Besides, a samples of washed finer limestone waste from a neighboring quarry defined as a 2-5 mm Russian fraction of fine aggregate of grading close to that for the largest Size of fine aggregate number 9 according to ASTM C 33 also was tested as a coarse aggregate of concrete. Physical properties of aggregates fractions 3-10 and 2-5 are the same. It was made for estimation of change of concrete strength depending on the change of grading of small grains crushed limestone used as a coarse aggregate of this concrete. Moreover, comparison of concrete strength of samples with coarse aggregate of the different grading allows estimation the change of strengths of concrete caused by a possible breakdown of this aggregate due to handling and transportation from quarry to aggregate

bin of concrete plant. Results of sieve analysis of this aggregate (Russian fraction 2-5mm) are presented in Table 4.

Table 4

	Dimensions of Square Openings(mm)						
	5.0	2.5	1.25	0.63	0.315	0.16	under 0.16
Sieve residue (%)	20.5	69.5	8.75	0.45	-	-	0.8
Amount finer than each laboratory sieve (%)	79.50	10.00	1.25	0.8	0.8	0.8	

To estimate compressive strength of concrete with washed limestone waste of fractions 3-10 and 2-5 mm as a coarse aggregate standard cubes 10x10x10cm were made with the use of Portland cement Brand 500-DO-N of the Oscol cement plant without admixture. According to the Russian building practice of production of precast concrete cubes were subjected to standard steam-curing according to following pattern; 3+3+6+4, i.e. 3 hrs of conditioning, 3 hrs of the temperature rise to 80°C, 6 hrs of isothermal warming, and 4 hrs of cooling. One-day compressive strength of steam-cured concrete makes up 60-65% of 28-day strength of this concrete. 28-day compressive strength of steam-cured concrete makes up 90% of 28-day strength of concrete of natural maturing. Test results of compressive strength of concrete brought to the standard European cube 15x15x15cm and corresponding estimations of cylindrical strength (psi) are presented in Table 5. Cylindrical strength of concrete is estimated to be 1.2 times less than the cubic strength of this concrete. Concrete mixes number 1, 3, 5 were made with enriched waste defined as a Russian fraction 3-10 mm (Table 3) as a coarse aggregate, mixes number 2, 4, 6 were made with an aggregate defined as a Russian fraction 2-5 mm (Table 4) as a coarse aggregate.

Table 5

Number	Composition of ready-mixed Concrete (kg/m^3)				Density of mix (kg/m^3)	Slump (cm)	Cubic compressive strength Mpa / Cylindrical compressive strength psi	
	Cement	Sand	Coarse aggregate	Water/ cement ratio			1 day	28 days
1	198	751	1,068	1.05	2,225	6.5	5.8/690	10.0/1190
2	197	740	1,066	1.05	2,210	7.0	4.8/570	8.0/950
3	347	596	1,091	0.61	2,245	8.0	19.4/2,310	29.0/3,450
4	350	580	1,100	0.60	2,240	8.5	17.9/2,130	28.3/3,370
5	498	478	1,075	0.43	2,265	7.5	37.1/4,420	42.0/5,000
6	500	483	1,060	0.42	2,255	9.0	31.1/3,700	38.4/4,570

As one can see from Table 5, the use of crushed limestone of Russian fraction 3-10 mm with the grading close to that for Size No.89 as a coarse aggregate for concrete allows to achieve compressive strength of concrete in the range from 1,000 to 5,000 psi. Finer crushed limestone of Russian fraction 2-5mm of grading close to that for the Size number 9 is less efficient as a coarse aggregate. Compressive strength of concrete with this coarse aggregate is less at least by 10% than that for concrete with coarse aggregate of grading close to that for the Size number 89.

All said above relates to concrete with coarse aggregate of washed limestone waste delivered to the Institute laboratory from the quarry without a change of its grading. It is necessary to estimate the actual breakdown of this aggregate due to transportation from quarry to plant and its impact on the concrete strength. The efficiency of the use of enriched limestone waste as a coarse aggregate in industrial conditions was checked at the Moscow plant of precast concrete No.10. Crushed limestone of the grading of Russian fraction 3-10 with water-absorption equal to 10% as a very vulnerable coarse aggregate was used for this aim. Ten double-side tipping wagons with 500 m^3 of enriched limestone waste were delivered from the Lavsk quarry to the concrete plant. Grading of this aggregate at the quarry is presented in Table 3. Results of sieve analysis of this limestone waste at the concrete plant are presented in the Table 6.

Table 6

	Dimensions of Square Openings(mm)							
	10.0	5.0	2.5	1.25	0.63	0.315	0.16	Under 0.16
Sieve residue (%)	2.4	30.6	58.7	3.0	0.9	1.66	2.2	0.54
Amount finer than each laboratory sieve (%)	2.4	67.0	8.3	5.3	4.4	2.74	0.54	-

As can be seen from the Table 6, grading of enriched limestone waste at the concrete plant considerably differs from the grading of this aggregate at the quarry after enrichment. It changes due to loading, autumn rains, and moving by bulldozers to aggregate bin after discharge from wagons on concrete pavement of the concrete plant store. The amount of aggregate finer than 5mm constituted near 1/3 of the total weight of aggregate before transportation to the concrete plant, while the amount of this aggregate at the concrete plant is close to the 2/3 of the total weight of aggregate. The main part of aggregate is finer than 5mm and coarser than 2.5mm. Grading of enriched limestone waste after transportation to the concrete plant can be considered close to intermediate between coarse and fine aggregates in Terminology of ASTM C125, i. e. between grading of Sizes number 89 and 9 according to ASTM C33.

The tests of concrete with limestone waste of this grading were carried out, the consumption of cement being the same as for prestressed piles. It was made to estimate maximum compressive strength of concrete with crushed limestone as a coarse aggregate of this grading. Concrete for piles is produced only with granite crushed stone as a coarse aggregate, and consumption of portland cement Brand 500-DO-N of the Volsk cement plant for this concrete is equal to 460 kg per cubic meter of concrete. The peculiarity of concrete for prestressed piles is the required one-day cubic compressive strength, which should be not less than 30 Mpa. This cubic strength corresponds to a cylindrical strength equal to 3570 psi. According to the Russian building practice of producing of precast concrete, cubes were subjected to the standard steam-curing according to next pattern; 3+3+6+4, i.e. 3 hrs of conditioning, 3 hrs of the temperature rise to 80°C, 6 hrs of isothermal warming, and 4 hrs of cooling. Test results of concrete are presented at the Table 7.

Table 7

Number	Composition of ready-mixed concrete (kg/m^3)					Slump (cm)	Cubic compressive strength Mpa Cylindrical compressive strength psi			
	Cement	Sand	Coarse aggregate	Water/ cement ratio	Admixture (%)		1 day		28 days	
							f cu	f cu avg	f cu	f cu avg
1	500	483	1060	0.324	-	6	20.9	22.60	29.9	30.60
							24.3	2,960	33.3	3,640
2	500	483	1060	0.308	0.5	7	21.8	21.10	30.4	29.45
							20.5	2,510	28.5	3,505
3	500	483	1060	0.420	-	8	20.9	20.65	39.9	39.45
							20.4	2,460	39.4	4,700
4	500	512	1110	0.370	-	6	23.8	24.50	46.5	46.05
							25.2	2,920	45.6	5,480
5	500	512	1110	0.280	0.3	6	41.8	42.00	46.1	47.75
							42.2	5,000	49.4	5,685
6	450	560	1110	0.280	0.3	6	35.6	34.80	40.9	40.40
							33.7	4140	39.9	4,810
7	400	610	1110	0.280	0.3	4	32.3	34.20	43.2	43.45
							36.1	4070	43.7	5,170

Three first series of test can be considered as attempts of fitting to very unusual coarse aggregate; crushed limestone was not used as a coarse aggregate on the plant. Four other series of test of this concrete should be considered as quite successful. Enriched limestone waste as a coarse aggregate after considerable breakdown caused by the handling and transportation to the concrete plant in the adverse weather conditions allows to obtain concrete of specified compressive strength up to 5,000 psi and even more.

The efficiency of enriched limestone waste of the certain grading as a coarse aggregate can be estimated by the compressive strength of concrete with this coarse aggregate. As can be seen from the Tables 5 and 7, enriched limestone waste of grading intermediate between the coarse and fine aggregate in Terminology ASTM C125 is more efficient as a coarse aggregate than crushed limestone of grading close to that for the Size No.89 and grading close to that for the Size No.9 according to the ASTM C33. Compressive strength of concrete with crushed limestone of this grading as a coarse aggregate is higher at least by the 10% than that for concrete of the same

consumption of cement with crushed limestone of grading close to that for the Size No.89 as a coarse aggregate. Compressive strength of this concrete is considerably higher than that for concrete of the same consumption of cement with crushed limestone of grading close to that for the Size No.9 as a coarse aggregate. Moreover, consumption of cement for concrete with crushed limestone as a coarse aggregate of grading intermediate between the coarse and fine aggregate in Terminology ASTM C125 is less at least by the 10% than that for concrete of the same compressive strength with crushed granite of regular sizes as a coarse aggregate. One-day concrete strength exceeding the required for prestressed piles was achieved with reduction of the consumption of cement by more than ten-percent less and the half as many consumption of admixture as compared with that for concrete with crushed granite as a coarse aggregate (Tables 5 and 7).

Thus, crushed limestone of the amount of aggregate finer than 4.75mm close to but not exceeding 2/3 of the total weight of aggregate, of the amount of aggregate finer than 4.75mm but coarser than 2.36mm in the range 55- 60% of the total weight of aggregate, of the amount of aggregate finer than 0.3mm not exceeding about 3% of the total weight of aggregate can be considered as a coarse aggregate of optimal grading in terms of compressive strength of concrete. This grading can be considered as intermediate between the coarse and fine aggregate in the Terminology ASTM C125. Concrete with crushed limestone of this grading as a coarse aggregate requires less consumption of cement and admixture than concrete of the same compressive strength with crushed granite and any hard rock aggregate of regular sizes as a coarse aggregates. Concrete with crushed limestone of this grading as a coarse aggregate requires less consumption of cement than concrete of the same compressive strength with crushed limestone of grading corresponding to that for Sizes number 89 and 9 according to the ASTM C33 as a coarse aggregate.

Variation of grading of enriched limestone waste is inevitable; it is in the nature of this material. Requirements for grading of enriched limestone waste as a coarse aggregate at the quarry after enrichment and in the aggregate bin of concrete plant should limit influence of variation of

grading of this aggregate on the strength of concrete. However, adverse conditions of transportation of this aggregate to the concrete plant can cause its excessive breakdown. It does not mean that enriched limestone waste of this grading can not be used as a coarse aggregate for concrete. However excessive breakdown of this coarse aggregate influences the strength of concrete. If the amount of aggregate finer than 4.75mm exceeds 2/3 of the total weight of aggregate in the aggregate bin, it means reduction of concrete strength. Additional consumption of cement requires for compensation of degradation of this aggregate.

Tests of concrete with the different grading of crushed limestone as a coarse aggregate allow to estimate the acceptable limits of variation of grading of enriched limestone waste as a coarse aggregate in aggregate bin of concrete plant. As can be seen from the Tables 5 and 7, compressive strength of concrete with crushed limestone of grading close to that for the Size No.9 is less at least by 10% than that for concrete with crushed limestone of grading close to that for the Size No.89. Compressive strength of this concrete is considerably less that for concrete with crushed limestone of grading intermediate between the coarse and fine aggregate in the Terminology ASTM C125. The use of enriched limestone waste of grading finer than that for the Size number 9 as a coarse aggregate should be considered as undesirable; additional breakdown of aggregate requires non-proportional increase of consumption of cement.

Flexural strength of concrete is important quality of concrete. As applied to the thickness design of concrete pavement, flexural strength is the main quality of concrete. Concrete with crushed limestone as a coarse aggregate of grading intermediate between the coarse and fine aggregates in the Terminology ASTM C125 can be considered as optimal in terms of flexural strength at least as compared with concrete with hard rock coarse aggregates of regular sizes. Compressive strength of concrete with this coarse aggregate is higher than that for concrete of the same consumption of cement with crushed granite of regular sizes as a coarse aggregate, and the increase of compressive strength of concrete means the increase of flexural strength of this concrete.

As the strength of any structural material flexural strength of concrete should be characterized by the specified value, design flexural strength being estimated as a part of specified flexural strength. American building code ACI 318 and documents of Portland Cement Association do not contain the definition of specified concrete flexural strength. Current of thickness design procedure of concrete pavements allows considering the modulus of rupture (MR) as a specified concrete flexural strength. According to said Portland Cement Association Engineering Bulletin (Thickness Design for Concrete Highway and Street Pavements, Portland Cement Association, EB109P), the modulus of rupture (MR) of concrete should be estimated as the average 28-day flexural strength. The value of flexural strength multiplied by 50 psi, which is less than the experimental estimation of the mean value of this strength but is nearest to it, should be chosen as the modulus of rupture (MR) of this concrete.

It is well known that flexural strength is not inherent quality of concrete as well as compressive strength. Compressive strength of concrete is the best studied quality of concrete, and it is very important to provide means for estimation of statistical characteristics of flexural strength of concrete by means of those for compressive strength of this concrete. Statistical characteristics of flexural strength of normal concrete in connection with those for compressive strength of this concrete were obtained by processing the data of the results of American tests of cylindrical compressive strength and flexural strength of concrete, and American and British tests of the compressive strength of modified cubes and the flexural strength of concrete (Sapozhnikov N. Safety of Precast Reinforced Concrete and Prestressed Structural Members by the Second Limit State (Serviceability Limit State). State Committee of Construction of the USSR Institute of Information, Moscow, 1991, Table 6, Fig. 8).

Statistical connections between compressive and flexural strength of concrete were estimated by the values of coefficient of correlation between these two types of concrete strength. Coefficients of correlation between the compressive and flexural concrete strength are equal to 0.831 and 0.865

for two big samplings of test results of 3650 standard cylinders and beams and 1107 modified cubes and standard beams, respectively. Connections between compressive and flexural concrete strength, which correspond to these values of coefficient of correlation, can be considered statistically significant. It allows the choice of modulus of rupture of concrete (MR) of concrete for thickness design of pavement depending on the specified compressive strength of this concrete.

Using the test result of 3,650 of standard cylinders and beams, the mean value of flexural strength of concrete f_r can be estimated depending on the mean value of cylinder compressive strength f_c as equal to $9.42\sqrt{f_c}$. This estimation of the mean value of flexural strength of concrete corresponds to the theoretical line of linear regression between compressive and flexural strength of concrete. It can be considered as legitimate at least in the range of the change of compressive strength from 2,500 to the 4,750psi; as can be seen from the Fig.8, theoretical and empirical lines of regression in this range of change of compressive strength coincide completely. Since the deviation of empirical line of regression from theoretical one is small up to compressive strength of concrete equal to 6,000psi, estimation of the mean value of flexural strength equal to $9.42\sqrt{f_c}$ can be considered as legitimate in the range of change compressive strength from 2,500 to 6,000psi.

Since the main estimation of compressive strength of concrete in American building practice is cylinder strength, the modified cube strength was assessed as cylinder by dividing by 1.2; the cubic strength of concrete is higher than that of cylindrical by 20% on average. Using the test results of 1107 of modified cubes and standard beams, the mean value of flexural strength of concrete f_r can be estimated depending on the mean value of modified cubes compressive strength of this concrete $f_{cu.mod}$ is equal to $9.53\sqrt{f_{cu.mod}/1.2}$. Estimations of the mean value of the flexural strength of concrete obtained depending on the mean values of the compressive cylindrical and modified cubes strength of this concrete brought to cylindrical strength are very close and can be considered adequate.

According to said American building code ACI 318, the mean value of compressive strength of concrete f_c considered as the required average strength f_{cr} in terms of the ACI 318 must exceed the

specified compressive strength fc' by at least 1.34S(fc), where S(fc) is the standard deviation of this strength. The values of the coefficient of variation for compressive and flexural strength of concrete are assumed usually as equal to 15% (Thickness Design for Concrete Highway and Street Pavements, Portland Cement Association, EB109P, p. 34). Basing on value of coefficient of variation equal to 15%, this excess can be estimated as 25% of value of specified compressive strength fc'. Thus, the mean value of compressive strength of concrete fc can be considered as corresponding to certain value of specified compressive strength fc'. Due to close statistical connections between the compressive and flexural strength of concrete, mean value of flexural strength of this concrete fr estimated as $9.42\sqrt{fc}$ can also be considered as corresponding to this value of specified compressive strength.

The value of flexural strength multiplied by 50 psi, which is less than the estimation of the mean value of this strength but is nearest to it, should be chosen as the modulus of rupture (MR) of this concrete. Values of specified compressive strength fc' equal to 3,000, 3,500, 4,000, 4,500 and 5,000 psi corresponds to the values of modulus of rupture (MR) equal to 550, 600, 650, 700, and 750 psi, respectively, coefficient of variation of compressive strength of concrete being assumed as 15%. These estimations of modulus of rupture of concrete are stable as to the change of coefficient of variation of compressive strength of concrete.

The large sampling of test results of 3650 standard cylinders and beams includes the 81 series of concrete samples of the same mix design. The coefficients of variation of compressive and flexural strength were estimated for all these series. The mean value of coefficient of variation of compressive strength of 81 series of test results of standard cylinder constitutes 10.95%. According to the requirements of ACI 318, required average strength should exceed specified compressive strength at least by 17%. Values of specified compressive strength fc' equal to 3,000, 3,500, 4,000, 4,500 and 5,000 psi corresponds to the values of the required average compressive strength equal to 3,510, 4,095, 4,680, 5,625, and 5,850 psi, respectively. The mean values of flexural strength corresponding

to these values of the required average compressive strength estimated by the plot of change flexural strength of concrete depending on the change of the compressive strength (Fig.8) are very close to 550, 600, 650, 700, and 750 psi, respectively.

As can be seen on the Fig.8, empirical and theoretical lines of regression do not coincide in the range of change of compressive strength of concrete from 1,000 to 2,000psi. The values of flexural strength of concrete in this range of the change of compressive strength are estimated as corresponding to the empirical line of regression. The values of compressive strength equal to 1,000, 1,500, and 2,000psi correspond to the values of flexural strength equal to 250, 350, and 450 psi, respectively. The volume of test results in this range of the change of compressive strength is not good enough for estimation of values of modulus of rupture depending on the specified compressive strength of concrete. Because of this, the values of flexural strength equal to 300, 400, and 450psi only approximately can be considered as the estimations of modulus of rupture corresponding to the values of specified compressive strength equal to 1,000, 1,500, and 2,000psi, respectively.

The foregoing estimations of the values of the modulus of rupture of concrete depending on the values of specified compressive strength f_c' of this concrete are based on the test results of concrete with all types of coarse aggregate of regular sizes. Considerable part of these aggregates relates to the hard rock (gravel, crushed gravel, and crushed granite). It is well known that flexural strength of concrete with this coarse aggregate is in the range from 10 to12 percents of compressive strength of concrete, and it increases up to the 15 percents of compressive strength for concrete with crushed limestone of regular sizes as a coarse aggregate.

It can be waited the higher flexural strength of concrete with small grains crushed limestone as a coarse aggregate than that for concrete of the same consumption of cement with crushed limestone of regular sizes as a coarse aggregate. It is possible due to more complete penetration of mortar into small grains crushed limestone and more uniform structure of concrete with this coarse aggregate than that for concrete of crushed limestone of regular sizes as a coarse aggregate. The first

flexural tests of concrete with crushed limestone as a coarse aggregate of grading intermediate between that for coarse and fine aggregate in the Terminology ASTM C125 confirm this tendency. In these tests the values of flexural strength of concrete equal to 418, 657 and 771 psi correspond to the values of compressive strength equal to 1,476, 2,821, and 4,166 psi, respectively. Flexural strength of concrete in these tests is in the range from 28.35 to 18.5 percents of compressive strength, diminishing with the increase of compressive strength. It does not mean the possibility of such estimations of modulus of rupture of concrete depending on the compressive strength of this concrete. There are only test results of the 3 series of two standard cubes brought to cylinder strength and two standard beams. However it means the tendency which should be checked during the mass production of concrete with crushed limestone of this grading for road construction.

An estimation of coefficient of variation of normal concrete strength equal to 15% is usually assumed and is incorporated into the design charts and tables of ACI and Portland Cement Association documents both for compressive and flexural strength. Concrete with enriched limestone waste as a coarse aggregate is more homogenous than concrete with crushed granite and crushed limestone of regular sizes as a coarse aggregate. The degree of uniformity of this concrete can be considered as intermediate between that for normal concrete with coarse aggregate of regular sizes and mortar. It means that the coefficient of variation of strength of concrete with the enriched limestone waste as coarse aggregate should be less than for concrete with coarse aggregate of regular sizes. Reduction of coefficient of variation of compressive strength of concrete means the possibility to reduce compressive average strength required according to said American building code ACI 318 with corresponding reduction of consumption of cement for this concrete.

The main peculiarity of concrete with limestone quarry waste as a coarse aggregate is the possibility of utilization of great deposits of crushed limestone finer than 9.5mm, and especially the part of this aggregate finer than 4.75mm. The minimum of aggregate finer than 4.75mm before enrichment constitutes near 1/3 of the total weight of aggregate, and it corresponds to very

vulnerable aggregate. The use of less vulnerable aggregate means the possibility of reduction of the amount of aggregate coarser than 4.75mm and corresponding increase of the amount of aggregate finer than 4.75mm before enrichment. Utilization of great deposits of limestone waste enables to reduce quarrying of high-quality aggregate with corresponding conservation of environment.

Concrete with crushed limestone of grading intermediate between the coarse and fine aggregates in the Terminology ASTM C125 was checked in industrial conditions. Crushed limestone of this grading was used as a coarse aggregate for concrete of precast reinforced concrete temporary road slabs 1.75x3.0x0.16m dimensions. More than 500 these slabs were produced on September-October 2002 at this plant. These slabs are used for access roads to buildings under construction. They are placed usually into mud without any subbase and work separately. Conditions of service of these slabs under extensive truck traffic are more than adverse. However there are no financial claims to plant connected with the strength of those slabs.

The use of concrete with this coarse aggregate allows very profitable utilization of great deposits of crushed limestone finer than 9.5mm usually estimated as limestone quarry waste and especially aggregate finer than 4.75mm. In so doing the volume of utilized aggregate finer than 4.75mm should constitutes at least 1/3 of the volume of utilized aggregate finer than 9.5mm.

OPERATION OF ADDITIONAL EMBODIMENT

The main aim of operation is to obtain concrete with enriched limestone waste as a coarse aggregate of grading optimal in terms of compressive and flexural strength of concrete. It means that in the aggregate bin of concrete plant the amount of aggregate finer than 4.75mm should be close to but not exceed 2/3 of the total weight of aggregate, the amount of aggregate finer than 4.75mm but coarser than 2.36mm should be about 55-60% of the total weight of aggregate, the amount of aggregate finer than 0.3mm should not exceed about 3% of the total weight of aggregate. Cost of aggregate finer than 9.5mm and coarser than 4.75mm depends on the proportion between amounts of

aggregate finer and coarser than 4.75mm before enrichment; cost of aggregate finer than 4.75mm is considerably less than that for aggregate coarser than 4.75mm.

Amount of aggregate finer than 4.75mm before enrichment should be not less than 1/3 of the total weight of aggregate. It is determined depending on the breakdown of this aggregate due to handling and transportation to aggregate bin of concrete plant. Since more coarse parts of aggregate are more vulnerable due to scale effect, breakdown of aggregate relates mainly to its part coarser than 4.75mm. Breakdown of aggregate depends on the its water-absorption, weather conditions, conditions of handling and transportation, and should be estimated experimentally. The breakdown of aggregate of ten-percent water-absorption under adverse weather conditions, adverse conditions of handling and transportation to aggregate bin of concrete plant results in the doubling increase of aggregate finer than 4.75mm. Breakdown of aggregate of less water-absorption should be less, and proportions between amounts of aggregate of finer and coarser than 4.75mm before enrichment and in aggregate bin of concrete plant should be closer. Moreover, breakdown of aggregate coarser than 4.75mm caused by screening as a dry enrichment of aggregate should be taking into account also.

Excessive breakdown of enriched limestone waste as a coarse aggregate causes reduction of concrete strength, which should be compensated by additional consumption of cement. Grading of crushed limestone finer than corresponding to the Size number 9 is consider as unacceptable for its utilization as a coarse aggregate since it requires increase of consumption of cement non-proportional to degradation of aggregate.

Enrichment can be carried out by washing or screening, or by combination of washing and screening. The aim of enrichment is reduction of is reduction of small size grains and to obtain the desirable proportion between the parts of aggregate. The choice of method of enrichment depends on the results of sieve analysis of this aggregate and the domestic conditions.

Mix design of concrete with crushed limestone of this grading should be carried out with the consumption of cement less by about 10% and twice less consumption of admixture than that

required for concrete of the same specified compressive strength with crushed limestone of regular sizes as a coarse aggregate. Batch plant corrections must be made for moisture in aggregates.

CONCLUSION

Composite concrete pavement includes the surface course of normal concrete and subbase and/or lower layer with compressive and flexural strength which can be no less than that for normal concrete of surface course. Coarse aggregate of subbase and/or lower layer concrete defined as enriched limestone waste is a washed by-product of manufacture of crushed limestone of ordinary Sizes number 56, 57, 6, and 67 with rated dimensions 25-9.5 mm, 25-4.75 mm, 19- 9.5 mm, and 19-4.75 mm, respectively. Enrichment of this aggregate should be carried out by washing or screening, or by combination of washing and screening. Method of enrichment depends on the grading of aggregate and should be selected by economical reasons.

Limestone quarry waste as a raw material for enrichment should be coarser than 9.5 mm and finer than 4.75mm. The amount of aggregate finer than 4.75 mm (Sieve No.4) before enrichment should be at least the value of the same order as for least Size of coarse aggregate number 89 according to ASTM C 33. It should be not less than 1/3 of total weight of aggregate. After enrichment the main part of aggregate finer than 4.75mm should be coarser than 2.36mm. The amount of aggregate finer than 2.36 mm (Sieve No. 8) should not exceed about 10%; the amount of aggregate finer than 1.18mm (Sieve No. 16) should not exceed about 7 %; the amount of aggregate finer than 300μm (Sieve No. 50) should not exceed about 2 %.

Grading of this aggregate at the quarry after enrichment and in the aggregate bin of concrete plant differs due to inevitable breakdown of aggregate caused by handling and transportation from quarry to concrete plant. Due to scale effect large grains are more vulnerable, and breakdown of aggregate relates mainly to part of aggregate coarser than 4.75mm. As a result, amount of aggregate finer than 4.75mm after transportation to aggregate bin of concrete plant should be increased. The breakdown of aggregate should be estimated experimentally and taking into consideration when

determining of proportion between parts of aggregate finer and coarser than 4.75mm before enrichment of this aggregate.

The amount of aggregate finer than 4.75mm in aggregate bin should be close to but not exceed 2/3 of the total weight of aggregate. The main part of aggregate finer than 4.75mm should be coarser than 2.36mm. The amount of aggregate finer than 300μm (Sieve No. 50) should not exceed about 2 %. Grading of enriched limestone waste in aggregate bin should be finer than the least Size of coarse aggregate number 89 and coarser than for largest Size of fine aggregate number 9 according to ASTM C 33. This grading can be considered as intermediate between the coarse and fine aggregates in Terminology of ASTM C125.

This grading of crushed limestone as a coarse aggregate can be considered as optimal in terms of concrete strength. Compressive strength of concrete with crushed limestone of grading corresponding to that for Sizes 89 and 9 as a coarse aggregate is less at least by 10% than compressive strength of concrete of the same consumption of cement with crushed limestone of this grading as a coarse aggregate. Moreover, compressive strength of concrete with crushed granite of regular sizes is less than compressive strength of concrete of the same consumption of cement and twice less consumption of admixture with crushed limestone of this grading as a coarse aggregate.

Variation of grading of enriched limestone waste is inevitable and excessive degradation of this aggregate should be considered as a possible. Excessive breakdown of aggregate does not mean impossibility of its use as a coarse aggregate for concrete. However it requires additional consumption of cement; grading of aggregate finer than corresponding to the Size number 9 is consider as unacceptable.

Enriched limestone waste is one of the cheapest aggregates. However, use of this aggregate allows obtaining concrete of specified compressive strength f_c' and modulus of rupture (MR) up to 5,000 and 700 psi, respectively. Using of this concrete for subbase and/or lower layer allows considerable reduction of thickness of normal concrete surface course; its thickness is determined by

the requirements for abrasion resistance of a normal concrete surface. The use of concrete of the different cost but of the same compressive and flexural strength for different parts of composite pavement allows to obtain composite concrete pavement of the equivalent normal concrete thickness equal to the physical one.

The use of very cheap and very efficient concrete with enriched limestone waste as a coarse aggregate for composite concrete pavement allows reduction of initial cost of construction of this pavement and makes this pavement more competitive as compared with asphalt pavement. Moreover, the use of concrete with this coarse aggregate allows very profitable utilization of great deposits of crushed limestone finer than 9.5mm usually estimated as limestone quarry waste and especially aggregate finer than 4.75mm. In so doing the volume of utilized aggregate finer than 4.75mm should constitutes at least 1/3 of the volume of utilized aggregate finer than 9.5mm. Utilization of limestone waste enables to reduce quarrying of high-quality aggregate with corresponding conservation of environment.